EFFECT OF UV INITIATOR ON DEVELOPING POLYMER-BASED COATING

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Abstract

Hydrogels have gained considerable attention globally due to their distinct ability to retain substantial amounts of water without structural alteration, making them valuable for application in diverse fields. This research investigates hydrogel formation, particularly emphasising the influence of crosslinkers, initiators, and exposure to UV intensity on the polymerisation process. Several hydrogel samples were made under different UV exposure durations to investigate the influence of exposure time on the polymerisation process.
It was revealed that when the sample was exposed to low-intensity UV light for a prolonged period, a range of structures, from crystalline to dehydrated forms, formed. In contrast, a high-intensity UV light failed to initiate the polymerisation process. The characterisation of the developed polymer samples was conducted by scanning electron microscope (SEM), energy dispersive X-ray (EDX), and fourier-transform infrared spectroscopy (FTIR).
The study focuses on the need for standardised procedures in hydrogel research and highlights the potential of these materials for sustainable building solutions. By establishing well-documented methods for hydrogel synthesis, this research proposes a foundation for future advancements in solar reflective coatings to reduce building energy consumption and enhance environmental sustainability.

Keywords: Polymer, UV Polymerization, Solar Reflective Coatings, Crosslinkers, Initiators.

1. INTRODUCTION

The building sector's carbon footprint contributes to climate change and the depletion of non-renewable resources, as buildings account for about one-third of the energy usage of the world. Additionally, maximum thermal control in buildings is through the HVAC systems, which consume significant energy resources (Verma and Rakshit 2023).
However, the utilisation of solar reflective coatings on building envelopes is one considerate strategy for achieving the goal of energy sustainability in the building construction sector. The energy-efficient building envelope is an interface between the inner and outer environment of the building, which encompasses properties like heat resistance, high insulation in windows, and effective control of vapour, helping to keep away from moisture (Barrett 2023). Moreover, anti-reflective coatings were used on the solar cells to enhance their efficiency optimised ability to absorb light and to retain the potential for reflecting light, which integrally resulted in a 15% improvement in energy conversion efficiency (Bretz, Akbari and Kurn 2008).

Additionally, building walls, when coated with highly solar-reflective external materials, show an effective measure to minimise the heat gains by solar radiation and help save cooling energy consumption as well (Zhang, Li, Long and Li 2017). Collins and Safiuddin (2022) created a superhydrophobic coating that reduced the adhesion of water and dust. This reduces the need for cleaning and maintenance. Hence, the coating also promotes environmental sustainability by enhancing energy efficiency and reducing waste in buildings (Mastalska-Popławska et al., 2022).

This research aims to prepare and investigate polymer-based solar reflective coatings for buildings and their potential to reduce energy consumption and promote sustainable building practices. This study focuses on the preparation of hydrogel due to its unique properties, including its three-dimensional networks of hydrophilic substances that absorb and retain large amounts of water. Furthermore, the synthesis process involves UV-induced polymerisation of a hydrogel precursor solution, and the properties of the resulting hydrogel are investigated. Furthermore, research has demonstrated that hydrogels can act as internal curing agents when in concrete, considerably mitigating shrinkage and cracking, which in turn prolongs service life (Peng et al., 2022). The main objective of this research is to study the formation of hydrogels using different combinations of crosslinkers and initiators under varied UV exposure conditions. It will reveal how these variables affect the properties of the hydrogel, particularly in terms of gel formation and their potential use in solar reflective coatings. Concurrently, the application of hydrogels in the construction industry has gained substantial emphasis because of its distinctive characteristics that enhance the functioning and resilience of building materials.

2. METHODOLOGY

2.1. Materials

Amid the fabrication of hydrogels, a range of diverse materials are frequently implemented to accomplish the required structural and functional properties. N-Isopropylacrylamide (NIPAAM), a monomer with a high purity of 97%, is frequently employed in hydrogel formulation, as reported by Sigma Aldrich. A subsequent resembling monomer, N-isopropylmethacrylamide (NIPMAAM), also with a purity of 97%, is used to provide a diversification in the polymer networks. To stabilise the hydrogel's structural integrity, crosslinkers such as N, N'-methylene bis(acrylamide) (MBAAm), with purity of 99%, are incorporated as well. Photoinitiators like 2-hydroxy-4'-(2-hydroxyethoxy)-2-methylpropiophenone (Irgacure 2959, 98%) are utilised to stimulate the polymerisation process when subjected to UV light, assisting the formation of the hydrogel matrix.
Deionised water is generally utilised as a solvent in such syntheses to make sure that the reaction environment is free from any kind of contamination. These materials go through rigorous characterisation to verify their composition and performance. Techniques such as Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS), and Fourier Transform Infrared Spectroscopy (FTIR) have been extensively used in several studies to provide analyses of the morphology, elemental composition, and molecular structure of the resulting hydrogel. The research conducted at the Advanced Materials Characterization Facility (AMCF) at Western Sydney University employed these analytical methods, yielding thorough and comprehensive insights into the structural features of synthesised hydrogels.

2.2. Hydrogel Preparation

The different compositions of hydrogel preparation are shown in Table 1.

Table 1. Mix design of hydrogel preparation.

Composition 1	Composition 2	Composition 3
NIPAAM- 578.13 mg NIPMAAm- 15.63 mg MBAAm- 31.25 mg Irgacure 2959- 12.5 mg Deionised Water- 10 ml	NIPMAAm- 480 mg (4.8%) MBAAm- 0.48 mg (0.1%) Irgacure 2959- 4.8 mg (1%) Deionised Water- 9.514 ml	NIPMAAm- 480 mg MBAAm- 0.0048 mg (2%) Irgacure 2959- 12.5 mg (1%) Deionised water- 9.505 ml

The desired quantity of raw materials was added into a beaker along with the required amount of deionised water to form a mixture while continuously stirring in a magnetic stirrer to achieve a 95.2 wt% solution. The vial was sealed to prevent the evaporation of the solvent covered in an aluminium foil for protection from the light and stirred overnight with the help of a magnetic stirrer until complete dissolution, ensuring a homogeneous mixture.

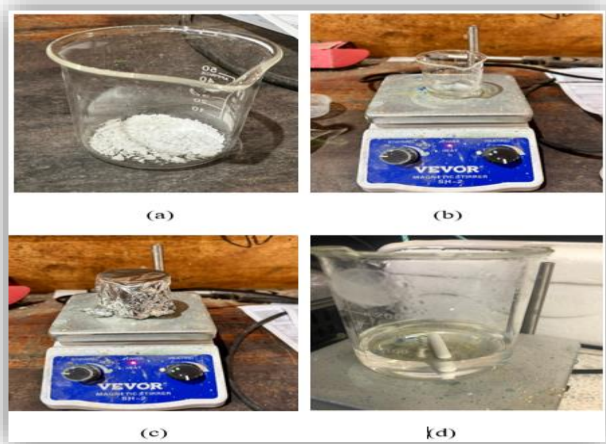

Figure 1. Preparation of the Hydrogel Precursor solution (a) Mixture of compounds, (b) Stirring in a magnetic stirrer, (c) Solution covered with foil (d) Hydrogel solution.

Figure shows the procedure for the preparation of the hydrogel precursor solution. The images in the figure are (a) a mixture of the desired quantity of compounds in the beaker, (b) mixing the materials with the help of a magnetic solution, (c) wrapping the mixture with an aluminium foil and leaving it under stirring in a magnetic stirrer and (d) hydrogel precursor solution.

2.3. UV Exposure and Polymerization

The prepared hydrogel solutions were exposed to UV light to initiate polymerisation. UV exposure was conducted under two conditions:

- Low-intensity UV light (0.5 W/m²): exposure times of 30 minutes, overnight, and 2 days.
- Dual-wavelength UV light (365 nm + 405 nm): exposure for 2 hours.

2.4. Characterisation

The formed hydrogels were characterised using the following techniques:

- SEM/EDS Analysis: To examine surface morphology and elemental composition of the hydrogels.
- FTIR Analysis: To identify functional groups present in the hydrogels and confirm successful polymerisation.

3. RESULTS

3.1. Gel Formation

- Composition 1

The hydrogel samples exposed to low-intensity UV light displayed varied degrees of gel formation. With increasing exposure time (from 30 minutes to 2 days), the samples exhibited increased crystallinity and dryness. Figure 2 shows the gel formation for the hydrogel solution made from composition 1.

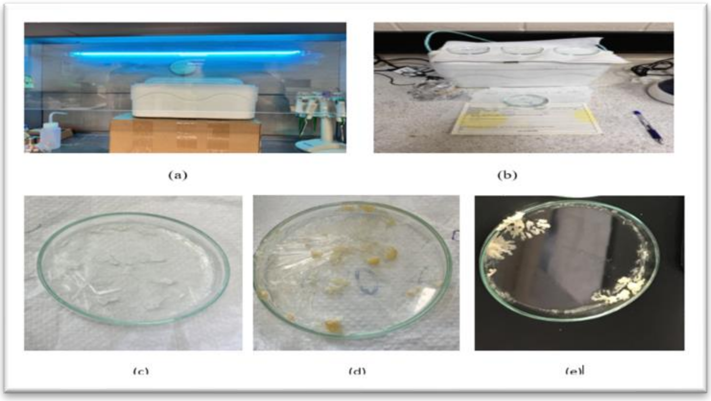

Figure 2. Gel formation from composition 1 (a) UV exposure (b) Samples to dry (c) Sample A (d) Sample B (e) Sample C

- Composition 2 and 3 (Dual-Wavelength UV)

Despite dual-wavelength UV exposure for 2 hours, no gel formation was observed in Compositions 2 and 3. This suggests that the composition of crosslinkers and the initiator may not have been compatible for effective polymerisation under these conditions. Figure 3 shows the gel formation for the hydrogel solution made from composition 1.

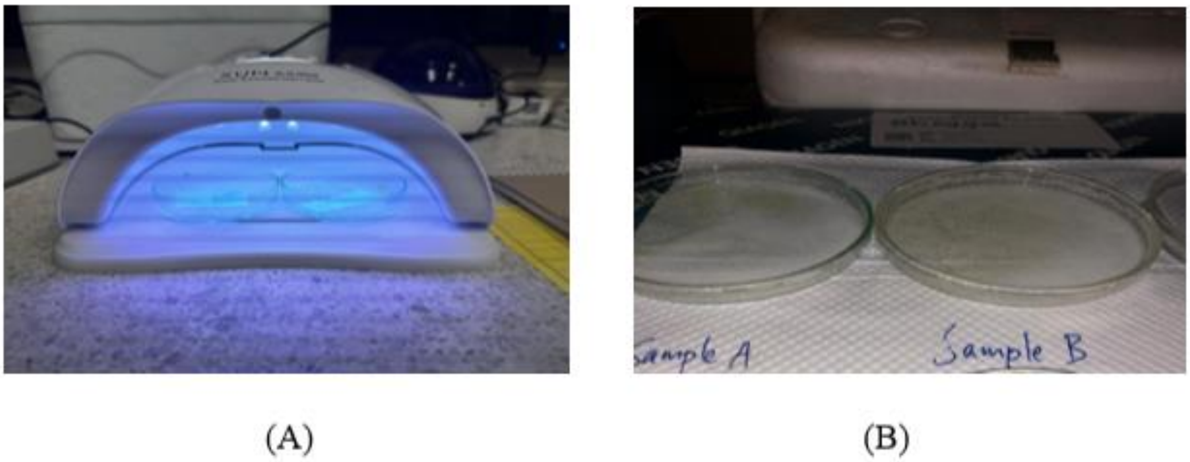

Figure 3 Gel formation for compositions 2 and 3 (A) Samples exposure to UV (B) After UV exposure result for composition 2 (sample A) and composition 3 (Sample B).

3.2. SEM/EDS and FTIR Analysis

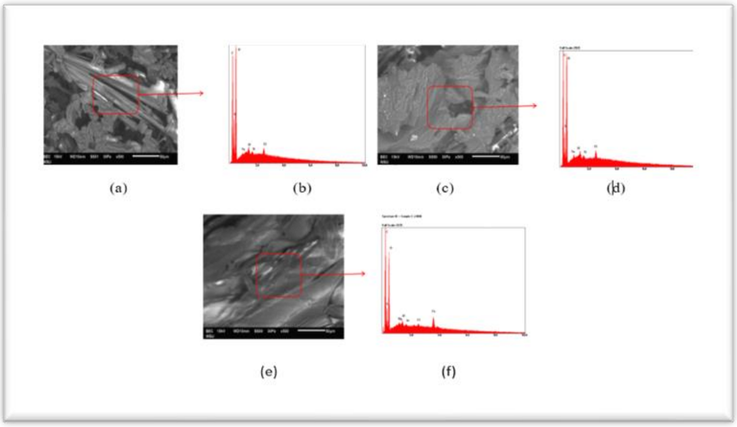

Figure 4. SEM/EDS images of hydrogel samples exposed to UV under different time intervals (a) SEM image of Sample A, (b) EDS spectra of Sample A, (c) SEM image of Sample B, (d) EDS spectra of Sample B, (a) SEM image of Sample C, (b) EDS spectra of Sample C.

Figure 4 shows the SEM images and corresponding EDS spectra of different hydrogel samples exposed to UV light at different time intervals. The figure consists of SEM images of hydrogel samples exposed to UV for 30 minutes (Sample A) (a), overnight (Sample B) (c) and 2 days (Sample C) (d) and their corresponding EDS spectra (b), (d) and (f) respectively.

The SEM images in the figure display the surface features and microstructure of the sample, magnified at x500, revealing particle sizes ranging up to 50 nanometers. When exposed to UV light, the sample exhibited different surface appearances depending on the duration of exposure. After 30 minutes of UV exposure, the sample displayed rod-like surface features (Figure 4a). Similarly, the sample exposed to UV overnight exhibited wood-like surface patterns (Figure 4c). In contrast, the sample exposed to UV for 2 days displayed dry and flaky surface features (Figure 4e). Notably, as the duration of UV exposure increased, the surface morphology appeared drier and flakier.

The EDS spectra display the intensities of chemical constituents in the sample. The EDS spectra of all samples indicated the presence of carbon (C), Nitrogen (N), and Oxygen (O), which are the primary constituents of the monomer used to prepare the sample. All the samples showed a small intensity of Aluminium (Al) and Silicon (Si) due to the use of Aluminium stubs to mount the samples.

3.3. FTIR Analysis

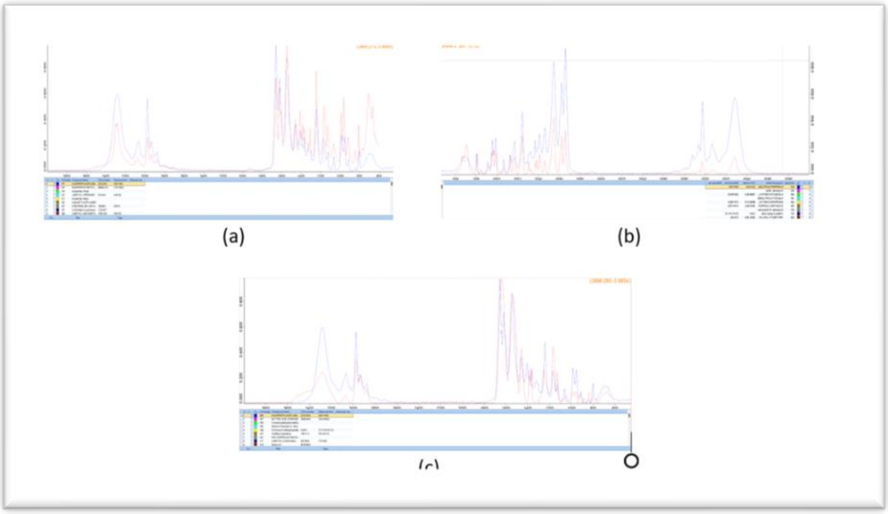

Figure 5. FTIR spectra of the hydrogel samples exposed to UV light for different time intervals (a) Sample A, (b) Sample B, (c) Sample C

Figure 5 shows the FTIR spectra of the Hydrogel samples exposed to UV for 30 minutes (a), overnight (b), and 2 days (c).

The FTIR analysis revealed that all samples closely matched the spectral pattern of N-Isopropylacrylamide, the primary monomer used in sample preparation. Each spectrum displayed two distinct peaks: a red peak representing the tested sample and a blue peak indicating the best library match. Sample C exhibited some discrepancies due to prolonged UV exposure, which caused water molecules to evaporate and resulted in changes in the compound's composition. In contrast, samples exposed for shorter durations maintained more consistent spectral characteristics. This emphasises the significant impact of UV exposure time on the stability and composition of the hydrogel material.

4. DISCUSSION

This study investigated the synthesis of hydrogels for solar reflective coatings, focusing on the effects of composition and UV exposure. Composition 1, when subjected to varying durations of low-intensity UV, the material exhibited increased crystallinity and drier, flaky structures with prolonged exposure. Furthermore, SEM/EDS analysis revealed significant changes in surface morphology, while FTIR analysis confirmed molecular alterations with extended UV exposure.

In contrast, Compositions 2 and 3 failed to form gels under dual optical wavelengths, indicating that the combination of crosslinkers, initiators, and UV intensity exposure is crucial for successful hydrogel formation. These findings emphasise the significance of optimising composition and polymerisation conditions to achieve the desired properties of the hydrogel. The mechanical properties of hydrogel effects by UV exposure resonates with the review by Clough et al. (2023), which discussed how high-energy radiation can enhance the cross-linking density of polymer networks.

Therefore, a comparison with existing studies highlighted the need for standardised procedures and clearer guidelines for hydrogel synthesis. Variations in material concentrations and inadequate temperature control documentation in previous research have posed challenges to reproducibility, reinforcing the need for detailed and consistent methodologies in future studies.

In relation to the environmental sustainability of hydrogels in the construction sector, the study builds on the findings by Peng et al. (2022). They demonstrated that incorporating polyacrylic hydrogels into concrete can improve its durability and reduce environmental impacts through effective internal curing. This supports our assertion that the optimal selection of polymer composition is important for enhancing the performance of solar reflective coatings. The parallels between the hydrogels in the study and those used in concrete suggest a broader applicability of hydrogel technologies in increasing material sustainability (Peng et al., 2022).

Furthermore, the incorporation of UV-responsive crosslinkers in hydrogel formulations not only improves mechanical characteristics but also potentially increases their fire-retardant properties, allowing expansion of the applicability of hydrogel coatings in energy-efficient sustainable building materials (Mastalska-Popławska et al., 2022). By contextualising the outcomes within the findings, it is emphasised that the significance of ongoing research in this area is to develop advanced materials that can contribute to sustainable practices in building design and energy efficiency.

5. CONCLUSION

This research demonstrates how composition and UV exposure critically impact hydrogel formation and properties. The findings reveal that more prolonged UV exposure leads to increased crystallinity and dryness in texture, while high intensity failed to form gels due to mismatches between crosslinkers, initiators, and dual wavelength UV intensity. These results underscore the importance of precise control over both material composition and external conditions to achieve optimal hydrogel properties.
Additionally, this study points out the need for standardised methodologies in hydrogel research, particularly in documenting material concentrations and UV exposure parameters. Overall, the research offers a pathway toward more energy-efficient building solutions through innovative hydrogel-based coatings, contributing to environmental sustainability goals by reducing building energy consumption and environmental impact. Future exploration should devolve into the large-scale application of this research in both residential and commercial building projects, with an emphasis on reducing maintenance expenses and improving the resilience of structural buildings under extreme thermal and environmental conditions. As supported by existing literature, the integration of hydrogel technology holds great promise for advancing construction practices and responding to modern preferences for sustainable practices (Peng et al., 2022; Mastalska-Popławska et al., 2022; Clough et al., 2023). Future research should focus on optimising hydrogel formulations to maximise their applicability in construction applications, paving the way for innovative and sustainable building solutions (Chen, H.2023).

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